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THE MAGNITUDE OF INTERNAL REWORK ON THE F-4 AIRCRAFT DURING DEP--ETC(U)
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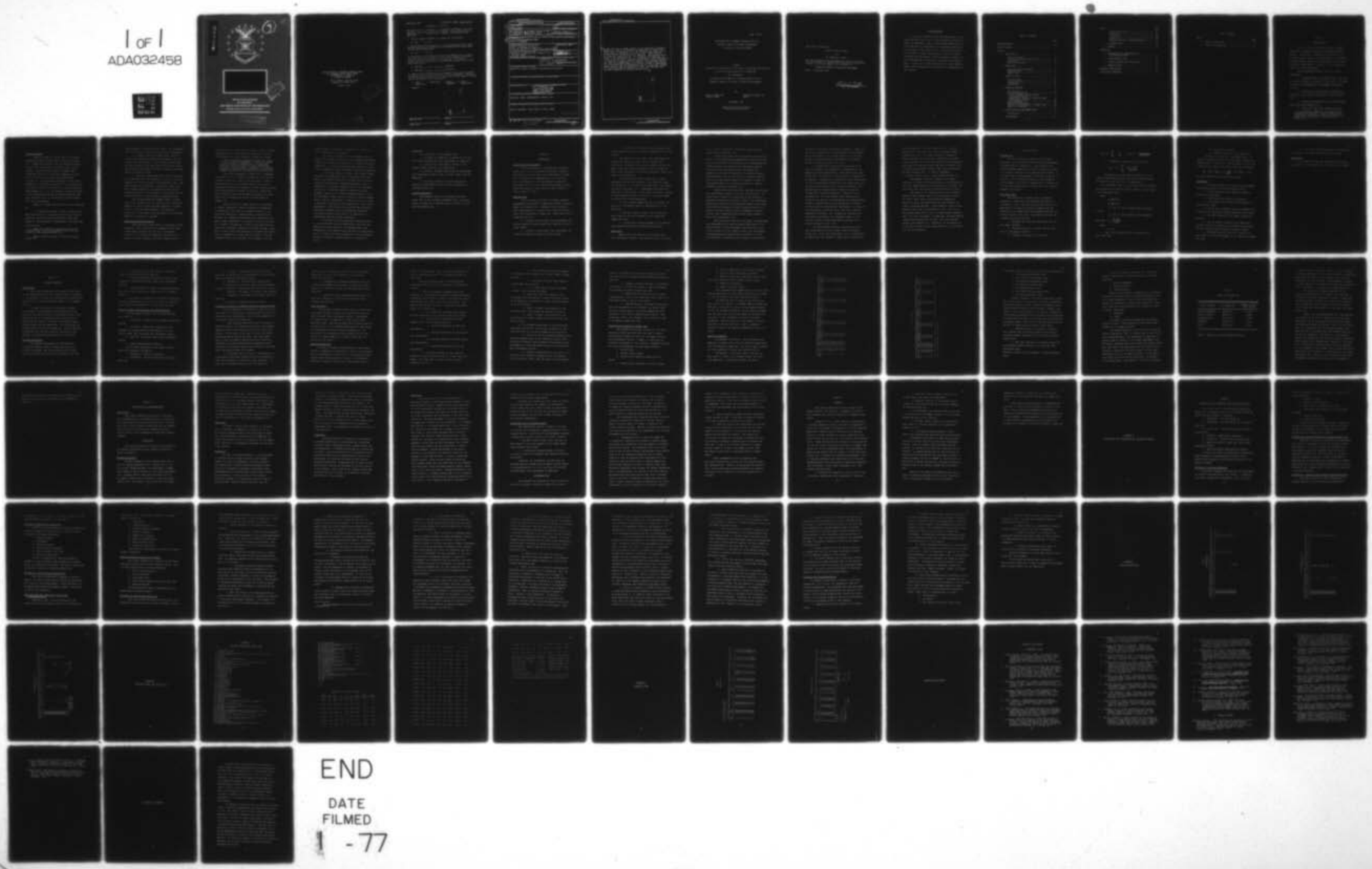

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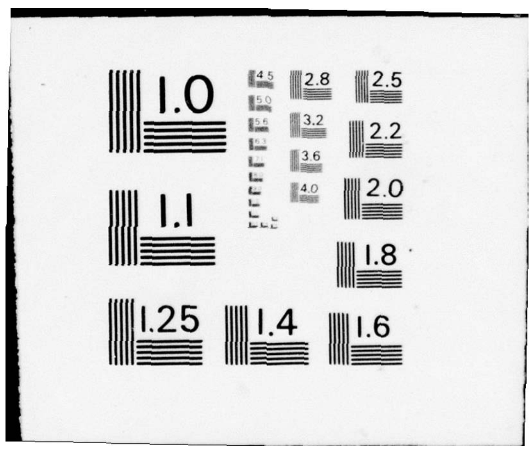
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Wright-Patterson Air Force Base, Ohio

THE MAGNITUDE OF INTERNAL REWORK ON THE
F-4 AIRCRAFT DURING DEPOT LEVEL
MAINTENANCE AT OGDEN AIR
LOGISTICS CENTER

John B. Berry, Captain, USAF
Raymond M. Hines, GS-12

SLSR 11-76B

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

14

1. REPORT NUMBER: SLSR-11-76B

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

9

4. TITLE (and Subtitle)

6

THE MAGNITUDE OF INTERNAL REWORK ON THE F-4 AIRCRAFT DURING DEPOT LEVEL MAINTENANCE AT OGDEN AIR LOGISTICS CENTER.

5. TYPE OF REPORT & PERIOD COVERED: Master's Thesis

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)

10

John B. Berry, Captain, USAF
Raymond M. Hines

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS

Graduate Education Division
School of Systems and Logistics
Air Force Institute of Technology, WPAFB OH

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

11

11. CONTROLLING OFFICE NAME AND ADDRESS

Department of Research and Communicative Studies (SLGR)
AFIT/SLGR, WPAFB OH 45433

12. REPORT DATE: Sep[redacted]76

13. NUMBER OF PAGES: 74

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

12 85p.

15. SECURITY CLASS. (of this report): UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

APPROVED FOR PUBLIC RELEASE AFR 190-17.

JERRAL F. GUESS, CAPT, USAF
Director of Information

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Internal, depot, maintenance, rework, cost

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Thesis Chairman: Major Paul F. Tully, USAF

Abstract on page a

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

012250

Abstract

In May 1975, Mr. J. Turk, Office of the Secretary of Defense, expressed a desire to estimate the magnitude of rework cost within AFLC to determine if it was of sufficient magnitude to warrant special attention in all services. Ogden ALC was selected as a test area for this research. The primary objectives of the research were: (1) determine the magnitude of rework cost for the F-4 aircraft during depot level maintenance, (2) identify the major areas of rework, their primary causes, and their cost magnitudes, (3) develop a standard methodology for identifying and classifying rework in terms of maintenance areas, causes, and cost magnitudes, and (4) stimulate interest for conducting similar research at other ALCs and TRCs with the major emphasis on reducing rework cost.

SLSR 11-76B

THE MAGNITUDE OF INTERNAL REWORK ON THE F-4 AIRCRAFT DURING DEPOT LEVEL MAINTENANCE AT OGDEN AIR LOGISTICS CENTER

A Thesis

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Logistics Management

By

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September 1976

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This thesis, written by

Captain John B. Berry

and

Mr. Raymond M. Hines

has been accepted by the undersigned on behalf of the faculty of the School of Systems and Logistics in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN LOGISTICS MANAGEMENT

DATE: 7 September 1976

Paul J. Tully
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ACKNOWLEDGMENTS

We wish to express our sincere appreciation to our thesis advisor, Major Paul F. Tully, Assistant Professor of Logistics Management, School of Systems and Logistics, Air Force Institute of Technology, for his guidance and direction throughout this thesis effort. We are also indebted to Mr. William A. Vincent, Deputy Chief, Aircraft Division, Directorate of Maintenance, Ogden Air Logistics Center, for his enthusiasm and cooperation in providing the required data. A final note of gratitude is given to Mrs. Marianne Ramsey, whose typing efforts assisted in the preparation of this thesis.

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Chapter 1

INTRODUCTION

The U. S. Air Force has directed that aircraft maintenance programs be based on three levels of maintenance: organization, intermediate, and depot (21:2). This maintenance concept is necessitated by the complexity of modern weapons systems, high maintenance costs, and a relatively fixed budget. The scope of this research was limited to depot maintenance.

Depot maintenance normally consists of four categories:

1. Programmed depot maintenance (PDM)--"the cycle or interval at which the aircraft is delivered to the depot facility for predesignated and programmed maintenance [14:25]."

2. Modification--"the process of updating the aircraft to the current technological state-of-the-art [20]."

3. Repair--"the renovation of an aircraft after major structural damage [20]."

4. Analytical conditional inspection (ACI)--

> the systematic disassembly and inspection of representative aircraft to locate hidden defects, deterioration conditions, corrosion, fatigue/overstress, etc., and failure in the structure or system [22:4].

Problem Statement

Ogden Air Logistics Center (ALC) is the prime Technological Repair Center (TRC) for the F-4 aircraft (24). Ogden ALC's Aircraft Division expends millions of dollars[1] each fiscal year in operating costs on these aircraft. There is some evidence to suggest that a significant portion[2] of total depot expenditure could be due to rework which occurs during maintenance (8;10;20;24). This percentage criterion of total depot expenditure is based upon a variance of two percent which the Aircraft Division is allowed on its monthly budgeted effectiveness (24). For this research, rework is defined as any maintenance which must be accomplished more than once (per depot visit) on a particular aircraft during depot level maintenance.

Examples of common events which fit this definition are:

1. A mechanic's failure to remove a plastic cap from the inlet port of the main refueling valve which he installed. This error was discovered two weeks later during the refueling phase of maintenance. The additional

---

[1]Based upon Ogden ALC's Operating Cost Report (GO35AHO3) from 1 July 1974 through 30 June 1975, the Aircraft Division expended $5,887,735.

[2]Greater than two percent of total depot maintenance cost.

work necessary to troubleshoot and correct the discrepancy can be attributed to rework caused by faulty workmanship.

2. During a Functional Check Flight (FCF) an aileron power control cylinder failed internally and the aircraft aborted because of flight control malfunctions. The work required to find and correct this problem (which may include an additional FCF) can be classified as rework caused by material failure.

3. Because a landing gear strut was not available for an aircraft which was scheduled to fly, the strut was cannibalized from an aircraft on the production line. The work required for the removal, installation (when a new strut became available), and operational check of the landing gear system of the aircraft on the production line can be attributed to rework caused by cannibalization.

The Air Force Logistics Command (AFLC) is aware that rework contributes to the overall cost of depot maintenance, but does not know the exact magnitude of rework cost (8). This research attempted to determine the proportion of total depot level maintenance cost which may directly be attributed to rework.

Justification and Delimitation

There has been a clear trend of increasing aircraft complexity. This trend has been accompanied by an equal or even greater increase in the cost of maintenance (9:1;25:1). In a period of budgetary constraints, cost becomes a critical element in military organizations. A

major objective of each ALC is to produce a quality product during depot level maintenance at minimum cost (23:2-1). In addressing this cost orientation, AFLCM 66-1 states:

> The philosophy and concepts of production control are used in workload management to give our customer a quality product at minimum cost. Planning and scheduling workload through the depot maintenance facility is not sufficient to minimize cost. Rather, management techniques must be employed to insure that planned workloads are followed and controlled [23:21].

Since depot management is predicated on management by exception (23:2-1), there is a tendency to be reactive instead of proactive. That is, the ALC tends to resolve problems after they occur rather than initially anticipating and preventing the problem. One such problem fitting this classification is rework (8;10;20;24). Rework cost and its potential solution are major concerns at all command levels, including the Office of the Secretary of Defense (8).

In May 1975, Mr. J. Turk, Office of the Secretary of Defense, expressed a desire to estimate the magnitude of rework cost within AFLC to determine whether it is of sufficient magnitude to warrant special attention by all services (8). Numerous studies have been conducted in the area of depot operations (1;2;3;4;8;9;11;12;13;14;17;18;19; 25). However, the majority of these studies have been concerned with individual components of weapons systems. While none of these studies were principally concerned with rework, they all tangentially touched upon the subject. From the literature review, this research effort appears to be the

first attempt to determine the magnitude of rework cost on the F-4 aircraft at Ogden ALC.

The initial benefactor of this research will be Ogden ALC's Aircraft Division. If this research can demonstrate that rework cost in Ogden ALC's Aircraft Division is significant, it would justify additional research to identify the corrective action necessary to rectify the problem.

If the major areas of rework, their primary causes, and their cost magnitudes can be identified, this information would provide Ogden ALC's Aircraft Division with a basis for developing and implementing improved control procedures. One possible approach would be the implementation of a 100 percent inspection system for quality assurance instead of the current sampling inspection (20). In this manner, rework could be isolated to faulty workmanship of specific individuals. Corrective action, in terms of additional training or closer supervision, could then be implemented. After corrective action had been initiated, inspection procedures could be readjusted accordingly. Cost/benefit analysis would have to be made prior to implementing improved control procedures.

If the results of the Ogden ALC's research justify it, similar efforts could be conducted at other ALCs and TRCs with the major objective of reducing rework cost. Consequently, this research could aid AFLC in accomplishing one of its major objectives during depot level maintenance, giving the customer a quality product at minimum cost (23:2-1).

Objectives

The objectives of this research were:

1. Determine the magnitude of rework cost for the F-4 aircraft during depot level maintenance at Ogden ALC.

2. Identify the major areas of rework, their primary causes, and their cost magnitudes.

3. Develop a standard methodology for identifying and classifying rework in terms of areas, causes, and cost magnitudes.

4. Stimulate interest for conducting similar research at other ALCs and TRCs with major emphasis on reducing rework cost.

Research Hypothesis

The research tested the following hypothesis: Rework cost for F-4 aircraft undergoing depot level maintenance at Ogden ALC is greater than two percent of total depot maintenance cost.

Chapter 2

METHODOLOGY

Universe/Population/Sample

For this research the universe was delimited to consist of all U. S. Air Force F-4 aircraft having the opportunity to receive depot level maintenance at Ogden ALC. The population encompassed all U. S. Air Force F-4s receiving depot level maintenance at Ogden ALC. The sample was 30 U. S. Air Force F-4s processed through Ogden ALC during the third quarter of FY75 (January 1, 1976 to March 31, 1976).

Sampling Plan

The 30 aircraft selected for a sample represent approximately ten percent of Ogden ALC Aircraft Division's annual F-4 workload (24). During the third quarter of FY75, approximately 75 aircraft were in various phases of depot level maintenance at Ogden ALC. These phases can be classified as (24):

1. Aircraft on which depot level maintenance was started during the second quarter and completed during the third quarter.

2. Aircraft on which depot level maintenance was started and completed during the third quarter.

3. Aircraft on which depot level maintenance was started during the third quarter and completed in the fourth quarter.

The aircraft on which depot level maintenance was started and completed during the third quarter were selected as the sample because when a request for data was made, these were the only aircraft for which records of depot level maintenance were readily available. Hence, the sample is opportunistic.

After an aircraft departs Ogden ALC, its depot maintenance records are maintained in an inactive status for six months. At the end of the sixth month, the records are usually destroyed (20). Arrangements were made with Ogden ALC to gain access to these inactive records. Instead of destroying the records at the end of six months, Ogden ALC mailed them to the researchers.

If the following assumptions can be verified, the results of the research should be generalizable to the population:

1. The major types of depot level work and the major types of tools and equipment do not appreciably change over time.

2. A continuing training program is used insuring that mechanics and inspectors maintain proficiency.

Sample Data

Sample data were extracted from inactive depot level maintenance records. Each inactive record is divided

into two major categories: predictable operations and unpredictable operations (20).

Predictable operations are negotiated work requirements for which engineering standards have been established. The work requirements were extracted by the Engineering and Planning Branch from pertinent F-4 maintenance manuals. After these work requirements have been defined and appropriate standards established by the Engineering and Planning Branch, the data are stored in the main computer. When the F-4 maintenance manuals are changed, revised, or supplemented and/or the standards revised, the computer program is updated accordingly (20).

Unpredictable operations are classified as additional work requirements unknown at the time of negotiation. The unpredictable operations become known as the aircraft is processed through various phases of depot level maintenance. Unpredictable operations are generated because of discrepancies discovered during an in-depth incoming inspection or because of rework caused by faulty workmanship, material failure, and/or cannibalization during various phases of depot level maintenance (20).

When an aircraft arrives at the depot, its negotiated work requirements have been previously established by the using activity, the system manager, and Ogden ALC. Prior to the aircraft's initial phase of depot level maintenance, the Engineering and Planning Branch releases to the Production Branch a computerized work package containing the

appropriate predictable operations necessary to comply with the specific negotiated work requirements on the aircraft. This work package is the primary element of the official records of depot maintenance performed on the aircraft during this particular depot visit (24).

As unpredictable operations become known by the Production Branch, the information is transmitted to the Engineering and Planning Branch. Some unpredictable operations may be stored in the computer under a "trigger-fix" subcategory. "Trigger-fix" operations are work requirements for which engineering standards have been established, but the work is not required on all aircraft processed. The Engineering and Planning Branch releases the specific "trigger-fix" documents necessary to comply with the discrepancies. For those unpredictable operations not stored in the computer, the Engineering and Planning Branch releases a computerized book containing control numbers which are used for tracking each discrepancy. In this book the discrepancy, corrective action, and actual manhours expended are recorded. The "trigger-fix" documents and the control book make up the secondary element of the official records of depot maintenance performed on the aircraft during its visit (20).

The major random variables addressed were total depot maintenance cost and internal depot maintenance rework cost. Total depot maintenance cost is operationally defined as the cost assessed to Ogden ALC's customers for

services rendered. Its major elements are: (a) direct labor cost, (b) material cost, and (c) an apportionment of overhead cost (20). In certain instances, elements of rework cost may also be included. Rework cost is operationally defined as the cost associated with any maintenance which must be accomplished more than once (per depot visit) on a particular aircraft during a depot level maintenance. Its major elements are: (a) faulty workmanship, (b) material failure, and (c) parts cannibalization (20).

The maximum conceptual strength of the random variables, in terms of value/data level, is continuous/ratio. After the random variables were classified for testing, the value/data level was discrete infinite/interval or ratio.

The values of the random variables were indirectly extracted from aircraft depot level maintenance records. All direct labor, which includes faulty workmanship, material failure, and cannibalization, was extracted in terms of expended manhours. Using industrial fund costing, manhours could then be converted into cost. That is, by multiplying direct labor hours to a predetermined budgetary rate, cost can be obtained. At Ogden ALC, the predetermined budgeted rate was $19.601 for FY75. This rate includes material and overhead (24). Therefore, by determining the direct labor hours for each random variable, its associated cost can be calculated.

DESIGN TO TEST

Criteria Test

For this research two percent of total depot maintenance cost was used as the criterion for determining the significance of rework cost. This criterion was selected because Ogden ALC's Aircraft Division is allowed a two percent variation on its budgeted effectiveness. It is assumed that a safety margin for possible rework is not included in the two percent variation. Since budgeted effectiveness is the ratio of budgeted cost to actual cost (24) and rework contributes to actual cost, the criterion appears to be logical.

Statistical Test

The statistical technique used to determine acceptance or rejection of the research hypothesis was the Student t test. This test was selected because it is appropriate (in terms of criteria for sample size and estimation of the sample mean and standard deviation) for interval or ratio level data. The approach utilized was to apply this test as follows:

1. Determine the total cost and rework cost for each sample aircraft.

2. Determine the ratio of rework cost to total cost for each sample aircraft.

3. Determine the mean of the 30 ratios.

$$\text{e.g., } \overline{X} = \sum_{i=1}^{30} \frac{X_i}{n} \quad \text{where } X_i = \frac{\text{rework cost}}{\text{total cost}}$$

4. Determine the variance of the 30 ratios.

$$\text{e.g., } S^2 = \sum_{i=1}^{30} \frac{\left[X_i - \overline{X}\right]^2}{n - 1}$$

Determination of acceptance or rejection of the research hypothesis was based upon the following decision rule applied at the .05 level of significance:

If t_s is greater than $t_{c,.05,29}$, reject H_0 and conclude that rework cost is greater than two percent of total depot level maintenance cost.

where:

$H_0: \mu_o \leq 2\%$

$H_1: \mu_o > 2\%$

t_c = the "t" value obtained from the Student t table

t_s = the "t" value computed from the sample data e.g., $t_s = \dfrac{\overline{X} - \mu_o}{s/\sqrt{n}}$

where:

$n = 30$

μ_o = the acceptable ratio of rework cost to total cost (2%)

$\overline{X}$ = as previously defined

s = standard deviation of the sample data

Based upon the results of the sample data, a 95 percent confidence interval was established to predict the expected mean of rework cost. The confidence interval was constructed by using the following statistical technique:

$$\mu_o = \overline{X} \pm \left[t_{\alpha/2,\ n-1} \right] \frac{S}{\sqrt{n}} \quad \text{where } \alpha/2 = .025$$

All other terms have been previously defined.

Assumptions

1. The major causes of rework are faulty workmanship, material failure, and parts cannibalization.

2. Rework caused by depot manager's erroneous decisions are negligible.

3. Rework caused by weather is negligible.

4. All mechanics and inspectors are qualified to perform their tasks.

5. Direct labor standards, material standards, and overhead do not appreciably change during the fiscal year.

6. The data contained in the sample records are accurate.

7. The two percent variation which Ogden ALC's Aircraft Division is allowed on its budgeted effectiveness does not include a safety margin for possible rework.

8. The major types of depot level work and the major types of tools and equipment do not appreciably change over time.

9. A continuing training program is used insuring that mechanics and inspectors maintain proficiency.

Limitations

If assumptions eight and nine cannot be verified, the results of this research will be limited to the sample.

Chapter 3

RESEARCH FINDINGS

Introduction

This chapter addresses the findings as they relate to the research hypothesis and objectives stated in Chapter 2. The material is presented in chronological sequence from data collection through analyzation phases of the research effort.

Although the process of developing a standard methodology for identifying and classifying rework was stated as the third objective of the research effort, this methodology had to be developed before rework could be identified and classified in terms of maintenance areas, primary causes, and cost magnitudes. The methodology was developed and is outlined in Appendix A. However, because of uncontrollable factors, which are discussed in this chapter, the standard methodology had to be modified.

Problems Encountered

The standard methodology for identifying and classifying rework, as shown in Appendix A, could not be followed as planned. The major uncontrollable factors which necessitated deviation from the research plan were:

1. Variations in the completeness of depot maintenance records received from Ogden ALC.

2. Diverse documentation procedures used by depot personnel in maintaining aircraft depot level maintenance records.

3. Time constraint in terms of obtaining additional data versus time available for completion of the research effort.

In an attempt to clarify why the planned methodology, outlined in Appendix A could not be followed, the uncontrollable factors are discussed in the next three sections.

Status of Sample Aircraft Depot Maintenance Records

For each sample aircraft, the following documents were complete:

1. G037D901-S1: Completed Serial Number Operations History,

2. G037D931L: Unpredictable Operations (that addressed the unscheduled work requirements of the Production, Radar, ATE, and Flight Test maintenance areas),

3. Form 335: Functional Check Flight Discrepancy Records,

4. Monthly Cannibalization Reports.

The following documents for each sample aircraft were either missing or incomplete:

1. G037D604-S1: Selected Operations,

2. G037D604-S2: Selected Operations for Special Major Jobs,

3. GO37D931L: Unpredictable Operations (which addressed the unscheduled work requirements of the Incoming, Paint, and Backshops maintenance areas),

4. GO37D941-S1: Selected Detail Descriptions.

In analyzing the status of sample depot maintenance records, the degree of completeness was defined as follows:

1. Complete: all pages of the report were received,

2. Incomplete: some pages of the report were not received,

3. Missing: the report was not received.

Documentation Status of Completed Depot Maintenance Records

With the exception of GO37D901-S1, there was little consistency in documentation of manhour expenditure data for unscheduled work requirements. The following examples are illustrative rather than exhaustive.

1. When analyzing cannibalization line entries in GO37D931L reports, the researchers discovered that manhour expenditure data were frequently omitted from these line entries. The accuracy of the data, on those line entries containing manhour expenditure data, were questionable. That is, when the manhour expenditure data documented on GO37D931L were checked against manhour expenditure data contained in the Monthly Cannibalization Report, there were minor variations between both figures.

2. Variations were also noted in documentation of discrepancies discovered during Evaluation and Inspection (E&I) and subsequently corrected by depot personnel. In some cases, although production count was taken for

correcting the discrepancy, corrective action and manhour expenditure data were not documented on the specific G037D931L line entry.

3. Documentation of manhour expenditure data for correcting discrepancies discovered after E&I were infrequent in the Production, Radar, and ATE maintenance areas' G037D931L.

4. Corrective action and manhour expenditure data were well documented on Flight Test maintenance area's G037D931L and Form 335.

Time Constraint

The problems enumerated above were not evident until an attempt was made to extract the required data from the sample aircraft depot maintenance records. Furthermore, the complex task of attempting to obtain omitted data, especially when it may have already been destroyed, resulted in modification of the standard methodology for identifying and classifying rework as outlined in Appendix A. The modification was necessary so this research could be completed in a timely manner but it had no effect upon the validity of the results.

Modified Methodology

In view of incomplete and missing depot maintenance records, documentation inconsistencies, and a time constraint, objective assignment of rework cost to the responsible maintenance areas was not possible. However, the researchers were able to identify rework cost by maintenance areas in

which it was discovered. That is, rework identified in a specific maintenance area is not necessarily caused by that area.

The modified methodology for identifying and classifying rework cost that was used by the researchers follows:

1. From the incomplete documents which were received, the researchers reconstructed master G037D604-S1, G037D604-S2, and G037D941-S1 reports for each Model Designator Series (MDS) (F-4C, F-4D, F-4E, and RF-4C). The specific methodology utilized to reconstruct each master report is outlined below:

a. All G037D604-S1 documents which address selected operations on F-4C aircraft were consolidated.

b. The G037D604-S1 documents were then separated into the following categories:

(1) Selected operations for PDM work requirements,

(2) Selected operations for modification work requirements,

(3) Selected operations for major repair work requirements,

(4) Selected operations for ACI work requirements.

c. From each category the most complete G037D604-S1 report was selected and all others were discarded. The steps used to select the most complete G037D604-S1 follow:

(1) Each G037D604-S1 report was examined to determine which document had the least number of pages missing.

(2) The report with the least number of missing pages was selected.

(3) If more than one report was found in Step 1, selection was arbitrary.

d. When these steps were completed, the researchers had reconstructed a master G037D604-S1 report which addressed all categories of depot level maintenance on the F-4C aircraft.

e. Steps a through d were repeated in the reconstruction of G037D604-S2 and G037D941-S1 reports.

f. Steps a through e were repeated in the reconstruction of master reports for the F-4D, F-4E, and RF-4C aircraft.

2. The standard methodology for identifying and classifying rework cost, as outlined in Appendix A, was then used after the following changes were incorporated.

a. Rework cost in the Incoming, Backshops, and Paint maintenance areas was not identified because those sections of G037D931L which addressed the unscheduled work requirements of these maintenance areas were missing from depot maintenance records.

b. Instead of analyzing each line entry of the G037D931L which addressed unscheduled work requirements in the Production, Radar, ATE, and Flight Test maintenance

areas of discrepancies discovered after E&I, only those line entries which contained manhour expenditure data were analyzed.

d. Whenever reference was made to G037D604-S1, G037D604-S2, or G037D941-S1 reports of specific aircraft, the reconstructed master reports were used.

e. Rework cost was identified by the maintenance areas in which it was discovered rather than by the maintenance areas in which it was caused.

f. Cannibalization: when manhour expenditure data were documented on the G037D931L line entry, these data were checked against the manhour expenditure data documented in the Monthly Cannibalization Report. When variations existed, the average of both figures was used as the manhour expenditure data.

Extraction and Analysis of Sample Data

The standard methodology, as modified, for identifying and classifying rework was then used to extract rework manhour expenditure data from the sample aircraft depot maintenance records. A sample of these data are contained in Appendix B. The contents of Appendix B include the following information for each sample aircraft:

1. Aircraft MDS,
2. Aircraft serial number,
3. Unpredictable operation numbers used for rework,
4. Classification categories of rework causes,

5. Manhour expenditure in each rework category,

6. Areas in which rework was discovered,

7. Number of additional Functional Check Flights (FCF)--air aborts were not included in this figure,

8. Number of air aborts,

9. Number of ground aborts.

This information was summarized and the total depot manhour expenditure for each sample aircraft was included to form the computer data input depicted in Table 1.

By using the logic outlined in the "Statistical Test" section of Chapter 2, a FORTRAN computer program was developed to perform the required calculations necessary to test the research hypothesis. As the computer program read the input data file and performed the necessary calculations, it also segregated the results by rework categories. Thus, the results of the computer run were also used to satisfy Objectives 1 and 2. Appendix C contains a copy of the computer program and a copy of its output.

Results of Analysis

The purpose of Objective 1 was to determine the magnitude of rework cost for the F-4 aircraft during depot level maintenance at Ogden ALC. For the 30 sample aircraft the total magnitude of rework cost was $214,029.20.

The purpose of Objective 2 was to identify the major areas of rework, their primary causes, and their cost magnitudes. As previously stated, the major

Table 1

Computer Input Data

Sample Number	Aircraft MDS	Aircraft Serial Number	Rework Manhours Caused by Faulty Workmanship	Rework Manhours Caused by Material Failure	Rework Manhours Caused by Cannibalization	Rework Manhours Caused by Flights	Rework Manhours Caused by Other Factors	Total Manhrs. Expended on Aircraft
1	F-4C	64-0928	36.9	283.6	34.6	146.3	27.0	9997.0
2	F-4D	65-0660	79.1	158.4	35.9	66.5	22.0	9332.0
3	F-4D	65-0730	52.1	128.8	9.0	66.5	4.6	4785.0
4	F-4D	66-7465	141.2	235.4	0.0	159.6	46.9	5714.0
5	F-4D	66-7483	29.2	61.1	17.9	53.2	7.0	9219.0
6	F-4D	66-7529	176.3	163.2	2.3	119.7	171.5	5233.0
7	RF-4C	64-1002	33.4	74.6	7.3	0.0	9.0	7542.0
8	RF-4C	65-0931	86.6	254.2	15.8	106.4	77.8	6604.0
9	RF-4C	65-0938	66.9	85.2	0.0	66.5	24.1	5441.0
10	RF-4C	65-0940	61.5	42.2	21.8	0.0	10.0	5630.0
11	F-4E	66-0300	147.9	171.4	28.5	146.3	63.7	9653.0
12	F-4E	66-0320	108.3	367.1	0.0	239.4	23.6	10340.0
13	F-4E	66-0334	26.1	46.2	.5	0.0	6.5	8935.0
14	F-4E	66-0345	31.0	158.2	15.8	39.9	50.5	10568.0
15	F-4E	66-0355	281.7	145.6	50.1	93.1	35.7	10875.0
16	F-4E	66-0356	69.1	71.2	5.5	39.9	88.4	11381.0
17	F-4E	67-0213	100.0	145.2	0.0	133.0	53.0	11110.0
18	F-4E	67-0231	74.3	106.6	44.0	66.5	9.0	10392.0
19	F-4E	67-0241	23.0	76.5	24.4	39.9	5.1	10619.0
20	F-4E	63-0309	139.1	75.3	18.3	39.9	31.0	8978.0

Table 1 (continued)

Sample Number	Aircraft MDS	Aircraft Serial Number	Rework Manhours Caused by Faulty Workmanship	Rework Manhours Caused by Material Failure	Rework Manhours Caused by Cannibalization	Rework Manhours Caused by Flights	Rework Manhours Caused by Other Factors	Total Manhrs. Expended on Aircraft
21	F-4E	67-0313	119.3	177.4	23.0	39.9	0.0	9096.0
22	F-4E	67-0316	73.5	164.2	23.0	39.9	9.0	15174.0
23	F-4E	67-0327	30.0	88.0	0.0	66.5	25.0	10390.0
24	F-4E	67-0341	64.8	73.0	9.3	226.1	28.5	8598.0
25	F-4E	67-0395	89.5	141.0	2.5	0.0	24.0	13630.0
26	F-4E	67-0396	19.5	112.2	71.6	0.0	9.0	10547.0
27	F-4E	67-0420	68.4	390.5	44.6	159.6	95.3	10048.0
28	F-4E	69-7556	154.4	117.5	4.0	119.7	32.8	10040.0
29	F-4E	69-7560	32.0	59.2	13.0	39.9	7.0	8480.0
30	F-4E	69-7574	128.3	140.0	0.0	199.5	29.5	9311.0

Source: Ogden ALC's Depot Maintenance Level Records.

maintenance areas in which rework could have occurred were:

1. The Incoming maintenance area,
2. The Production maintenance area,
3. The Backshops maintenance areas,
4. The Radar maintenance area,
5. The ATE maintenance area,
6. The Flight Test maintenance area,
7. The Paint maintenance area.

However, because of the factors previously discussed, rework could not be precisely assigned by responsible maintenance areas. Instead, rework was assigned by maintenance areas in which it was discovered. However, this does not effect the validity of the results. Analysis of rework manhour expenditure data indicated that the majority of rework was discovered in the Flight Test and Production maintenance areas. There were two primary reasons why the majority of rework was discovered in these areas.

1. Cannibalization line entries in G037D931L, when combined with the Monthly Cannibalization Report, contained adequate information for the Production maintenance area.

2. The first time that all aircraft systems are operationally checked together is in the Flight Test maintenance area.

Therefore, rework was only assigned to these maintenance areas.

An initial assumption was made that the primary causes of rework could be classified into the following categories:

1. Faulty workmanship,
2. Material failure,
3. Cannibalization.

However, as discussed in Appendix A, it is possible that some rework should not be classified exclusively into one of these categories. This was true when rework was caused by a combination of these three categories. Therefore, fourth and fifth categories were included as causes of rework. These were:

4. Reflights
5. Other

In terms of rework cost magnitudes, the results depicted in Table 2 were obtained for each rework cause category for the sample aircraft.

The primary purpose of this effort was to test the research hypothesis. That is, rework cost for the F-4 aircraft undergoing depot level maintenance at Ogden ALC is greater than two percent of total depot maintenance cost. The results indicated that total rework cost was $214,029.20 and total depot level maintenance cost was $5,442,453.00. Therefore, rework cost was 4.243 percent of total depot maintenance cost for the sample aircraft. To determine if this figure was statistically significant, the Student t test was performed. The computed t value was 4.574 which

Table 2

Rework Cost Magnitudes

Rework Category	Cost Magnitude	Percent of Total Depot Rework
Faulty Workmanship	$49,853.20	23.293
Material Failure	$84,539.10	39.499
Cannibalization	$10,245.40	4.787
Reflights	$49,271.00	23.021
Other	$20,120.40	9.401

Source: Ogden ALC's Depot Maintenance Records.

is greater than the critical t value of 1.699. Therefore, the rework percentage of 4.243 was statistically significant. Based upon the results of the Student t test, the null hypothesis (H_0) was rejected. The researchers concluded the data supported the finding that rework cost was greater than two percent of total depot level maintenance cost.

The statistical technique described in the "Statistical Test" section of Chapter 2 was then used to establish a 95 percent confidence interval for predicting the expected mean of rework cost. The results indicated that the expected mean of rework cost would be between 3.240 percent and 5.246 percent of total depot level maintenance cost.

Finally, the Klomogorov-Smirnov test was performed to determine if the ratio of rework cost to total depot maintenance cost of the population from which the sample was drawn was normally distributed. Use of the Lilliefors Table, in conjunction with the Klomogorov-Smirnov test, permitted use of the sample mean and standard deviation in the test for normality. The results of the Klomogorov-Smirnov test showed that the data were normally distributed with a mean of 4.2431 percent and a variance of 7.214 percent. The specific calculations are outlined in Appendix D. The variance of 7.214 percent does not mean that rework varied from -2.971 percent to 11.457 percent of total depot maintenance cost. This test only indicated the data used are normally distributed with the specified parameters.

These results concluded the findings of the research effort. Specific conclusions and recommendations are addressed in Chapter 4.

Chapter 4

CONCLUSIONS AND RECOMMENDATIONS

Introduction

This chapter addresses the specific conclusions and recommendations of the research effort in relation to the research hypothesis and stated objectives. The three major topics include specific conclusions for the research hypothesis and stated objectives, generalizations of research results, and recommendations based upon research findings.

CONCLUSIONS

This section includes the specific conclusions for the research hypothesis and each research objective as stated in Chapter 1.

Research Hypothesis

The major emphasis of the research effort was to test the research hypothesis (H_1): Rework cost for the F-4 aircraft undergoing depot level maintenance at Ogden ALC is greater than two percent of total depot maintenance cost. Research results indicated that rework cost for the sample aircraft was 4.24 percent of total depot maintenance cost. The Student t test proved that this figure

was statistically significant. Therefore, the null hypothesis (H_0) was rejected and the researchers concluded that rework cost for the sample aircraft was greater than two percent of total depot maintenance cost. Furthermore, the researchers predict, with 95 percent confidence, that if conditions in Ogden ALC's Aircraft Division do not change, the expected mean of rework cost will range from 3.24 percent to 5.246 percent of total depot maintenance cost.

Objective 1

In order to satisfy this objective, it was necessary to determine the magnitude of rework cost for the F-4 aircraft undergoing depot level maintenance at Ogden ALC. Research results indicated that the magnitude of rework cost was $214,029.20 (4.243 percent) for the sample data. Therefore, the researchers concluded that Objective 1 was achieved.

Objective 2

In order to achieve Objective 2, it was necessary to identify the major areas of rework, their primary causes, and their cost magnitudes. However, because of the uncontrollable factors previously discussed, rework could not be assigned by responsible maintenance areas. Recommendations for reducing these uncontrollable factors are discussed in the final section of this chapter. Rework was assigned to the maintenance areas in which it was discovered. Research results indicated that the

majority of rework was discovered in the Production and Flight Test maintenance areas. Procedures for assigning rework to the responsible maintenance areas are discussed in the "Recommendations" section of this chapter. The primary causes of rework were classified as: faulty workmanship, material failure, cannibalization, reflights, and other. Cost magnitudes by primary causes were: $49,853.20 (23.29%), $84,539.10 (39.50%), $10,245.40 (4.79%), $49,271.00 (23.02%), and $20,120.40 (9.40%), respectively. With the exception of assigning rework by responsible maintenance areas, the researchers concluded that Objective 2 was achieved.

Objective 3

Satisfying Objective 3 required the development of a standard methodology for identifying and classifying rework in terms of maintenance areas, primary causes, and cost magnitudes. A standard methodology was developed and although it required modification for the research effort, the modifications were not necessitated by flaws in the methodology, but rather by the uncontrollable factors previously identified. Recommendations for reducing these uncontrollable factors are discussed in the final section of this chapter. Since flaws in the standard methodology developed could not be found, the researchers concluded that Objective 3 was achieved.

<u>Objective 4</u>

The fourth objective of this research was to stimulate interest in conducting similar research at other ALCs and TRCs with major emphasis on reducing rework cost. It is the researcher's opinion that the ground work for achieving this objective has been laid through rejection of the null hypothesis and achievement of the first three objectives. Through achievement of the first objective, the magnitude of rework cost was determined to be a significant portion of total maintenance cost. This could serve as a stimulus to the Ogden ALC to expand on this research and attempt to develop and implement ways to reduce or eliminate the causes of rework identified here. Since rework cost was found to be significant in this research, managers of other ALCs and TRCs may suspect their rework costs are also significant and be motivated to conduct similar research. Through achievement of the second objective, this research could serve as a guide for the managers of other ALCs and TRCs to follow in conducting similar studies. Since the major areas of rework and their primary causes have been identified by this research, this should save others performing similar studies a great deal of time, cost, and effort. Through achievement of the third objective, a standard methodology, for use throughout the Air Force, for identifying and classifying rework costs could result. Other organizations may be encouraged to

perform similar research once the existence and value of a standard methodology are demonstrated.

Although this research involved a specific type of aircraft and a specific ALC (Ogden), the researchers believe enough similarity exists between the maintenance techniques used at this ALC and other maintenance organizations throughout the Air Force to make the results of this research transferable.

Generalizability of Research Results

The "Limitations" section of Chapter 2 outlines the criteria for determining the generalizability of the research results. Interviews with key management personnel at Ogden ALC's Aircraft Division (5;15;16;24) revealed:

1. The major types of depot level work and the major types of tools and equipment do not change appreciably between fiscal years.

2. A continuing training program is actively utilized to insure that mechanics and inspectors maintain proficiency.

Therefore, the researchers concluded that the research results obtained from the sample aircraft appear to be generalizable to all U. S. Air Force F-4 aircraft receiving depot level maintenance at Ogden ALC.

RECOMMENDATIONS

This research has demonstrated that the deviation from the two percent criterion in Ogden ALC's Aircraft

Division is statistically significant. These findings justify additional research to identify the corrective actions necessary to rectify the problems. In addition, the Ogden ALC research findings justify the expenditure of similar research efforts at other ALCs and TRCs with the major objective of reducing rework cost within AFLC.

The researchers also recommend additional follow-on research be conducted at Ogden ALC's Aircraft Division using a different sample to attempt to replicate the current research findings. However, to reduce the uncontrollable factors encountered by the researchers, the following recommendations are offered:

1. Arrangements should be made with Ogden ALC to standardize documentation procedures of manhour expenditure data for unscheduled work requirements in G037D931L and Form 335 reports. The schedulers would be the focal point in such an effort because they maintain these reports. Since it is the schedulers responsibility to document production count on completed work requirements for each operation, they must have access to manhour expenditure data for each operation in order to complete their task. Therefore, schedulers could document the manhour expenditure data on the appropriate line entries of the above reports. This additional step would require very little increased effort on the part of schedulers because when production count is taken, they must stamp the appropriate line entry. Schedulers could also coordinate with aircraft foremen to

minimize the occurrence of depot personnel correcting discrepancies without documenting the corrective actions in the appropriate reports. Until these procedures become routine, top management could establish a screening procedure to verify that the procedures are being complied with on each aircraft.

2. When a request for sample aircraft depot maintenance records is made to Ogden ALC, the specific reports as outlined in Appendix A, should be requested.

3. When the aircraft depot maintenance records are received by the researchers, an inventory should be performed as soon as possible to verify that the required reports are available and complete. The sooner this verification is completed, the higher the probability that the missing or incomplete documents can be obtained from Ogden ALC. If any of the required reports for a sample aircraft cannot be located, that sample aircraft depot maintenance record should be excluded from the research sample.

These recommendations do not guarantee that additional uncontrollable factors will not surface during any research effort. However, by minimizing the uncontrollable factors which were encountered during this research, the probability of success for follow-on research should increase.

Chapter 5

SUMMARY

This chapter summarizes the major events of the research effort. The material is presented in chronological sequence from research conception to research culmination.

In May 1975, Mr. J. Turk, Office of the Secretary of Defense, expressed a desire to estimate the magnitude of rework cost within AFLC to determine if it was of sufficient magnitude to warrant special attention in all services. With Mr. J. Turk's statement as a basis, Ogden ALC's Aircraft Division was selected as a test area for this research effort. Ogden ALC was selected because it is the prime TRC for the F-4 aircraft and there was evidence to suggest that rework cost for F-4s undergoing depot level maintenance at Ogden ALC was greater than two percent of total depot maintenance cost. Therefore, the research was designed to test the research hypothesis that rework cost for F-4 aircraft undergoing depot level maintenance at Ogden ALC was greater than two percent of total depot maintenance cost. The primary objectives were:

1. Determine the magnitude of rework cost for the F-4 aircraft during depot level maintenance at Ogden ALC.

2. Identify the major areas of rework, their primary causes, and their cost magnitudes.

3. Stimulate interest for conducting similar research at other ALCs and TRCs with the major emphasis on reducing rework cost.

It was determined the research results would have to be restricted to the sample aircraft if the following assumptions could not be verified:

1. The major types of depot level work and the major types of tools and equipment do not appreciably change over time.

2. A continuing training program is used to insure that mechanics and inspectors maintain proficiency.

Arrangements were made with Ogden ALC's Aircraft Division to acquire inactive aircraft depot maintenance records. From the aircraft depot maintenance records received, 30 records were selected as a data base for the research. A standard methodology was then developed for extracting the necessary data from the sample records. A computer program, written in FORTRAN IV, was developed to perform the necessary calculations. The major statistical technique used in the computer program was the Student t test.

Results of the computer program were then used to accept the research hypothesis and to achieve Objectives 1 and 2. Based upon information received from key

management personnel at Ogden ALC, the findings were generalized to the population from which the sample was drawn.

Based upon the research results, recommendations were made to conduct similar research at other ALCs and TRCs. Finally specific recommendations were made for reducing the uncontrollable factors which were encountered in this research. It was emphasized that implementation of these specific recommendations should increase the probability of success for follow-on research at Ogden ALC.

APPENDIX A

METHODOLOGY FOR IDENTIFYING AND CLASSIFYING REWORK

APPENDIX A

METHODOLOGY FOR IDENTIFYING AND CLASSIFYING REWORK

The initial step of identifying and classifying rework cost is gaining access to the following records and reports for each aircraft of interest.

1. G037D604-S1: Selected Operations,

2. G037D604-S2: Selected Operations for Special Major Jobs,

3. G037D901-S1: Completed Serial Number Operations History,

4. G037D931L: Upredictable Operations,

5. G037D941-S1: Selected Detail Descriptions,

6. Ogden ALC Form 335: Functional Check Flight Discrepancy Records,

7. Ogden ALC Monthly Cannibalization Reports.

To assist the reader in acquiring the working knowledge necessary for understanding how rework cost is identified and classified, each record and report will be briefly discussed.

G037D604-S1: Selected Operations

This report contains the scheduled work requirements that should be accomplished on the aircraft. In addition, it includes "trigger-fix" requirements. Each line entry,

numerically arranged by operation number, contains the following information:

1. Operation number,
2. General task description,
3. Type of skill required for the task,
4. Maintenance area responsible for task accomplishment,
5. Standard task time,
6. Production count date.

G037D604-S1 is maintained by aircraft schedulers in each major maintenance area (Incoming, Production, Radar, Automatic Test Equipment (ATE), Flight Test, and Paint) through which the aircraft are processed.

G037D604-S2: Selected Operations for Special Major Jobs

G037D604-S2 contains the scheduled work requirements which should be performed on an aircraft because of major modifications. It can also include the scheduled work requirements on parts and equipment which are routed to Backshops for bench work. Each line entry of the report contains information identical to that in G037D604-S1. Depending upon the maintenance area responsible for performing the specific work requirements addressed in the report, G037D604-S2 can be maintained by either the shop schedulers or aircraft schedulers.

G037D901-S1: Completed Serial Number Operations History

This report contains the daily expenditure of standard manhours for both scheduled and unscheduled

maintenance. The last page of the report contains the total standard manhours expended on the aircraft.

GO37D931L: Unpredictable Operations

GO37D931L contains unscheduled work requirements for which no "trigger-fix" documents exist. Each line entry contains the following information:

1. Operation number,
2. Discrepancy,
3. Corrective action,
4. Standard manhours expended,
5. When discrepancy discovered,
6. Production count date.

A block of unpredictable operation numbers is assigned to each maintenance area through which aircraft, parts, or equipment are processed. The report is maintained by aircraft schedulers in each maintenance area.

GO37D941-S1: Selected Detail Description

This report is numerically arranged by operation number. For each operation number step-by-step procedures are listed for task accomplishment. These procedures are extracted from pertinent maintenance manuals. This report is used by line mechanics.

Ogden ALC Form 335: Functional Check Flight Discrepancy Record

Form 335 is used to record discrepancies and corrective actions on aircraft released to the functional

check flight crew. The records contain the following general information:

1. Discrepancy,
2. Corrective action,
3. Standard manhours expended,
4. Number of flights,
5. Number of air aborts,
6. Number of ground aborts,
7. When discovered date,
8. Production count date.

This record is maintained by the Flight Test area's aircraft schedulers.

Ogden ALC Monthly Cannibalization Report

This report summarizes all aircraft related cannibalization actions which occurred during the month. Each line entry contains the following information:

1. Date of cannibalization,
2. Item stock number,
3. Item nomenclature,
4. Total monthly cannibalization for each item,
5. Manhours expended.

The cannibalization report is maintained by the Scheduling and Inventory Branch.

Procedure for Identifying Rework Cost

When these records and reports are available, the researcher should study their contents thoroughly. After

the researcher becomes familiar with this information, he can use the following steps to identify rework cost. These steps must be used for each aircraft of interest.

1. Select G037D931L for the specific aircraft of interest.

2. Select the section of G037D931L which addresses the unscheduled work requirements of the Incoming maintenance area. There will be a section of G037D931L for each maintenance area through which aircraft are processed. Each line entry should address one of the following categories of unscheduled maintenance:

a. Cannibalization--This entry will specify: item part number, item nomenclature, and cannibalization date. The manhours expended for the cannibalization action may also be included.

b. Discrepancy discovered during incoming evaluation and inspection (E&I)--Discrepancies will be specified by an individual line entry indicating discovery during E&I. Manhours expended to correct the discrepancy should also be documented on the line entry. This category of unscheduled maintenance should not be used in rework calculations unless the discrepancy is corrected and subsequently cause rework.

3. Each line entry of the Incoming maintenance area's G037D931L must be analyzed to determine the category of unscheduled maintenance addressed. The category will determine which of the following substeps the researcher should use:

a. Cannibalization--Manhours expended for cannibalization action can be extracted from the line entry if they have been documented. If they are not documented, Ogden ALC Monthly Cannibalization Report must be used to obtain the information. Since the date of cannibalization and the item nomenclature are known, the manhours expended can be obtained by finding the item nomenclature in the specific Monthly Cannibalization Report. The manhours expended will be documented on the line entry of the Monthly Cannibalization Report containing the item nomenclature.

b. Discrepancy discovered during E&I--The line entry can be disregarded.

c. Discrepancy discovered after E&I--The Incoming maintenance area's G037D604-S1 and G037D941-S1 must be used to determine if the discrepancy can be identified as rework. For the researcher to identify a discrepancy as rework, he must determine if the discrepant item was disturbed[1] during depot level maintenance. If the item was disturbed, the discrepancy should be identified as rework. Determination can be made by complying with the following steps:

(1) Examine each line entry of G037D604-S1 until an entry is found in which the task could have caused the discrepant item to be disturbed or until all entries have been exhausted.

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[1]Any maintenance action which would cause an item to malfunction.

(2) If a line entry of G037D604-S1 addresses a task which could have caused the discrepant item to be disturbed and production count has been taken for the task, extract the operation number from the entry and obtain G037D941-S1.

(3) Since G037D941-S1 is arranged numerically by operation number, the pages addressing a specific operation number can easily be located. Locate the operation number of interest and read all pages it addresses. Since all steps and procedures necessary for the specific task accomplishment are listed, the researcher can determine if the discrepant item was disturbed. If the item was disturbed, the manhours expended to correct the discrepancy can be extracted from the specific line entry of G037D931L on which the discrepancy is documented. If the manhours expended have not been documented, the information can be obtained from Ogden ALC Engineering and Planning Branch.

(4) If all the entries of G037D604-S1 are exhausted without finding a task which could have caused the discrepant item to be disturbed, then each line entry of G037D931L which addresses discrepancies discovered during E&I must be examined to determine if correcting any of these discrepancies could have caused the discrepant to be disturbed. If an E&I discrepancy was corrected and subsequently malfunctioned, correcting the malfunction should be identified as rework. To determine the manhours expended to correct the discrepancy, use Step 3c(3).

(5) If all the entries of G037D604-S1 and G037D931L (discrepancies discovered during E&I) are examined without finding a task which could have caused the discrepant item to be disturbed, then each preceding line entry of G037D931L addressing discrepancies discovered after E&I must be examined determining if the discrepant item was disturbed while these discrepancies were being corrected. If a discrepancy discovered after E&I was corrected and subsequently malfunctioned, correcting the malfunction should be identified as rework. Manhour expenditure can be determined by using Step 3c(3).

d. Repeat Step 3 for each line entry of G037D931L. When all entries are exhausted, the researcher should know the total manhours expended on rework in the Incoming maintenance area.

4. Select the section of G037D931L addressing the unscheduled work requirements of the Backshops. Each line entry must be examined to determine which category of unscheduled maintenance is involved so that rework can be identified. Identification of rework can be accomplished by following Step 3 for each line entry of the Backshop's G037D931L. However, G037D604-S1 must be used instead of G037D604-S2. That is, wherever G037D604-S1 appears in Step 3, replace it with G037D604-S2. In addition, a determination must be made that none of the work in the Backshops is rework caused by other maintenance areas before the parts or equipment were routed to the Backshops. This

determination can be made by checking each line entry of the Backshop's G037D931L against the other maintenance areas' work documents by using Step 3c(1) through 3c(5). When all entries of the Backshop's G037D931L are exhausted, the researcher will have the total manhours expended on rework in the Incoming maintenance area and in the Backshops.

5. Select the section of G037D931L addressing the unscheduled work requirements of the Production maintenance area. To identify rework in this maintenance area, follow Step 3 for each line entry. In addition, the researcher must also perform Steps 3c(1) through 3c(3) using G037D604-S2 instead of G037D604-S1 to determine if a discrepant item was disturbed during a major job. To identify rework discovered in the Production maintenance area which originated in other maintenance areas, each line entry of Production maintenance area's G037D931L must be checked against the work documents of other maintenance areas using Steps 3c(1) through 3c(5). When all entries of Production maintenance area's G037D931L are exhausted, the researcher will know the total manhours expended on rework in the Incoming, Backshops, and Production maintenance areas.

6. Select the section of G037D931L which pertains to Radar maintenance area's unscheduled work requirements and perform Step 3. To identify rework discovered in the Radar maintenance area which was caused by other maintenance areas, each line entry of Radar maintenance area's G037D931L must be checked against the work documents of

other maintenance areas using Steps 3c(1) through 3c(5). At this point, the researcher will have the amount of manhours expended on rework in Incoming, Backshops, Production, and Radar maintenance areas.

7. Select the section of G037D931L addressing the unscheduled work requirements of the ATE maintenance area and accomplish Step 3. Identify rework discovered in ATE which originated in other maintenance areas by checking each line entry of ATE's G037D931L against the work documents of other maintenance areas using Steps 3c(1) through 3c(5). The researcher will then know the total manhours expended on rework in Incoming, Backshops, Production, Radar, and ATE maintenance areas.

8.a. Select the section of G037D931L addressing the unscheduled work requirements for the Flight Test maintenance area and accomplish Step 3.

b. Select Ogden ALC Form 335 for the specific aircraft of interest and check each entry against the work requirements of each maintenance area using Step 3. If the researcher is thoroughly familiar with the work requirements of each maintenance area, the time required to accomplish this step can be reduced significantly. In reading the discrepancy and corrective action, entered on Form 335, the researcher should be able to determine which maintenance area caused the discrepancy. Therefore, he can examine the work documents of the specific maintenance area instead of examining the work documents of all maintenance areas.

9. Select the section of G037D931L addressing the unscheduled work requirements of the Paint area and accomplish Step 3. Identify rework discovered in the Paint area which originated in other maintenance areas by checking each line entry of the Paint area's G037D931L against the work documents of other maintenance areas using Step 3c(1) through 3c(5). When this task is completed, the researcher will know the manhours expended on rework in each major maintenance area.

10. Select G037D901-S1 for the specific aircraft of interest and from the last page of the report extract the total manhours expended on the aircraft.

11. To convert manhour data to cost data, multiply the manhour data by Ogden ALC sales rate for the specific fiscal quarter in which the aircraft was processed through the depot. The sales rate can be obtained by contacting Ogden ALC's Engineering and Planning Branch.

Procedure for Classifying Rework

As rework is identified, it should be classified immediately. If it is not, the researcher's task will increase tremendously. The researcher must use some degree of subjectivity in classifying rework into specific categories. The following categories and criteria are illustrative of five rework categories which can be used and the criteria for assigning rework to each category.

1. Cannibalization--This category is self explanatory.

2. Material Failure--Some subjectivity may have to be used in assigning rework to this category. Generally when the researcher reads a discrepancy and its corrective action, he can determine if the discrepancy was caused by material failure. This determination can be made by analyzing the corrective action taken to correct the discrepancy. Discrepancies requiring corrective actions such as removed and replaced, or removed, repaired, and reinstalled would fit this category.

3. Faulty Workmanship--Determining if rework should be assigned to this category will probably require the most subjectivity. After the researcher is familiar with the work requirements of each maintenance area, he can generally determine if the rework discrepancy was caused by faulty workmanship. Discrepancies requiring corrective actions such as adjusted, readjusted, tightened, retightened, torqued, retorqued, rigged, rerigged, cleaned, etc. should be classified in this category.

4. Refly--This category should be reserved for aircraft which must be reflown because of discrepancies discovered after the aircraft had been released to the functional check flight crew and the discrepancy cannot be traced specifically to one of the above mentioned categories of rework. These types of discrepancies will cause:

a. Ground aborts,

b. Air aborts,

c. More than one functional check flight.

5. Other--At times it may not be possible to assign rework into any of the mentioned categories because of impracticabilities such as:

a. Rework caused by a combination of cannibalization, material failure, and faulty workmanship,

b. Items were removed to facilitate other maintenance and this maintenance cannot be traced directly to either cannibalization, material failure, or faulty workmanship,

c. Inflight discrepancies which cannot be duplicated on the ground by maintenance personnel.

Rework discrepancies of these types should be classified into this category.

By following this methodology, rework can be identified and classified in terms of responsible maintenance areas, primary causes, and cost magnitudes.

APPENDIX B

REWORK MANHOUR DATA

APPENDIX B

REWORK MANHOUR DATA

F-4C 64-0928

Operation Number	Faulty Workmanship	Material Failure	Cannibalization	Other	Area
99074			1.5		Production
99075			2.0		
99150			2.0		
99211			5.0		
99212			2.0		
99213			3.0		
99217			.5		
99218			1.5		
99220			2.0		
99221			3.0		
99222			1.5		
99223			3.0		
99239			1.5		
99240			3.5		
99520		4.0			Flight Test
99521		.5			
99522		4.0			
99524		25.0			
99529		6.0			
99531		4.5			

REWORK MANHOUR DATA (Continued)

F-4C 64-0928

Operation Number	Faulty Workmanship	Material Failure	Cannibalization	Other	Area
99533	4.0				Flight Test
99534		2.0			
99536		7.0			
99537		4.9			
99538		2.5			
99539		18.0			
99540	4.0				
99541	4.0				
99543		5.5			
99544		1.5			
99545		4.0			
99546		4.0			
99547		7.5			
99548		7.5			
99549		4.5			
99550		12.5			
99551		1.5			
99554	2.0				
99557	1.5				
99558	2.5				
99093		30.0			
99516	2.6				
99561	2.4				
99562	.7				

REWORK MANHOUR DATA (Continued)

F-4C 64-0928

Operation Number	Faulty Workmanship	Material Failure	Cannibalization	Other	Area
99563			2.6		Flight Test
99570	3.4				
99571		6.4			
99572		7.5			
99576		20.0			
99578		6.5			
99581		2.4			
99584		4.5			
99585	8.4				
99586		8.5			
99602				9.0	
99587				9.0	
99590		3.5			
99591	1.4				
99592		.9			
99593		1.5			
99596		18.5			
99598				9.0	
99599		45.0			
99600		1.5			
SUBTOTAL	36.9	283.6	34.6	27.0	

2 additional flights: 79.8
1 air abort: 39.9
1 ground abort: 26.6
Total Refly: 146.3

Subtotal: 382.1
Refly: 146.3
Total: 528.4

APPENDIX C

COMPUTER PROGRAM AND OUTPUT DATA

APPENDIX C

COMPUTER PROGRAM AND OUTPUT DATA

LIST

```
010 INTEGER SA(50),SN(50)
020 CHARACTER MA*3(50)
030 DIMENSION RW(50),RM(50),RC(50),RO(50),RF(50),TH(50),RT(50),RP(50)
031 DIMENSION RTM(50)
035 C=19.501
036 D=100.0
040 CALL ATTACH(11,"76A69/BERRY;",1,0,,)
050 DO 10 I=1,30
060 READ(11,100,END=200)LN,SA(I),MA(I),SN(I),RW(I),RM(I),RC(I),
061&RO(I),RF(I),TH(I)
070 RT(I)=(RW(I)+RM(I)+RC(I)+RO(I)+RF(I))*C
075 RTM(I)=RT(I)/C
080 RP(I)=(RT(I)/(TH(I)*C))*D
090 SRW=SRW+(RW(I))*C
100 SRM=SRM+(RM(I))*C
110 SRC=SRC+(RC(I))*C
120 SRO=SRO+(RO(I))*C
130 SRF=SRF+(RF(I))*C
140 SRT=SRT+RT(I)
150 SRP=SRP+RP(I)
160 STH=STH+(TH(I))*C
170 10 CONTINUE
180 RWP=(SRW/SRT)*D
190 RMP=(SRM/SRT)*D
200 RCP=(SRC/SRT)*D
210 ROP=(SRO/SRT)*D
220 RFP=(SRF/SRT)*D
230 XRP=SRP/30.0
240 DO 20 I=1,30
250 VRP=VRP+ABS((RP(I)-XRP))**2.0
260 20 CONTINUE
270 SD=SQRT(VRP/29.0)
280 TS=(XRP-2.0)/(SD/SQRT(30.0))
290 V0=XRP-(2.045*SD/SQRT(30.0))
300 V1=XRP+(2.045*SD/SQRT(30.0))
310 100 FORMAT(V)
311 PRINT 40,
312 40 FORMAT(//17X,"*****MANHOUR EXPENDITURE DATA*****",//)
313 PRINT 45,
314 45 FORMAT(4X,"ACFT",46X,"TOTAL")
315 PRINT 50,
316 50 FORMAT(4X,"SERIAL",2X,"WKMN",3X,"MAT",24X,"TOTAL",3X,
317&"EXPENDED",2X,"PERCNT")
318 PRINT 55,
319 55 FORMAT(4X,"NUMBER",2X,"SHIP",3X,"FAIL",3X,"CANN",2X,"OTHER",
320&2X,"REFLY",2X,"REWORK",2X,"MANHOUR",3X,"REWORK")
325 DO 30 I=1,30
330 PRINT 60,SA(I),SN(I),RW(I),RM(I),RC(I),RO(I),RF(I),RTM(I),
331&TH(I),RP(I)
340 60 FORMAT(/1X,I2,1X,I6,2X,F5.1,2X,F5.1,2X,F4.1,2X,
341&F5.1,2X,F5.1,2X,F5.1,3X,F7.1,3X,F6.3,//)
370 30 CONTINUE
380 PRINT 65,SRW,RWP
390 65 FORMAT(/"TOTAL FAULTY WORKMANSHIP COST:$",F9.1,5X,
400&"PERCENT OF REWORK:",F7.3,//)
```

```
410 PRINT 70,SRM,RMP
420 70 FORMAT("TOTAL MATERIAL FAILURE COST:   $",F9.1,5X,
421&"PERCENT OF REWORK:",F7.3,//)
430 PRINT 75,SRC,RCP
440 75 FORMAT("TOTAL CANNIBALIZATION COST:    $",F9.1,5X,
441&"PERCENT OF REWORK:",F7.3,//)
450 PRINT 80,SRO,ROP
460 80 FORMAT("TOTAL OTHER COST:              $",F9.1,5X,
461&"PERCENT OF REWORK:",F7.3,//)
470 PRINT 150,SRF,RFP
480 150 FORMAT("TOTAL REFLY COST:              $",F9.1,5X,
481&"PERCENT OF REWORK:",F7.3,//)
490 PRINT 85,SRT,XRP
500 85 FORMAT("TOTAL REWORK COST:             $",F9.1,5X,
501&"PERCENT REWORK:",F10.3,//)
510 PRINT 90,STH
520 90 FORMAT("TOTAL MAINTENANCE COST:        $",F9.1,//)
525 IF(TS.LT.1.699)GO TO 300
530 PRINT 95,TS
540 95 FORMAT("THE SAMPLE T STATISTIC:",F9.3,2X,
541&"IS GREATER THAN T CRITICAL OF 1.699",//)
570 300 CONTINUE
580 PRINT 110,V0,V1
590 110 FORMAT("USING 95% CONFIDENCE, THE PERCENTAGE OF REWORK ",
591&"SHOULD BE:",F5.3,"-",F5.3,//)
610 STOP
620 200 PRINT,"EOF"
630 STOP
640 END

ready

*RUN
```

*******MANHOUR EXPENDITURE DATA*******

	ACFT SERIAL NUMBER	WKMN SHIP	MAT FAIL	CANN	OTHER	REFLY	TOTAL REWORK	TOTAL EXPENDED MANHOUR	PERCNT REWORK
1	640928	36.9	283.6	34.6	27.0	146.3	528.4	9997.0	5.285
2	654660	79.1	158.4	35.9	22.0	66.5	361.9	9332.0	3.878
3	650730	52.1	128.8	9.0	4.6	66.5	261.0	4785.0	5.455
4	667465	141.2	235.4	0.	46.9	159.6	583.1	5714.0	10.205
5	667483	29.2	61.1	17.9	7.0	53.2	168.4	9219.0	1.827
6	667529	176.3	163.2	2.3	171.5	119.7	633.0	5233.0	12.096
7	641002	33.4	74.6	7.3	9.0	0.	124.3	7542.0	1.648

8	650931	86.6	254.2	15.8	77.8	106.4	540.8	[illegible]	8.189
9	650938	66.9	85.2	0.	24.1	66.5	242.7	5441.0	4.461
10	650940	61.5	42.2	21.8	10.0	0.	135.5	5634.0	2.407
11	660300	147.9	171.4	28.5	63.7	146.3	557.8	9653.0	5.779
12	660320	108.3	367.1	0.	23.6	239.4	738.4	10344.0	7.141
13	660334	26.1	46.2	0.5	6.5	0.	79.3	8935.0	0.888
14	660345	31.0	158.2	15.8	50.5	39.9	295.4	10568.0	2.795
15	660355	281.7	145.6	50.1	35.7	93.1	606.2	10875.0	5.574
16	660356	69.1	71.2	5.5	88.4	39.9	274.1	11381.0	2.408
17	670213	100.0	145.2	0.	53.0	133.0	431.2	11110.0	3.881
18	670231	74.3	106.6	44.0	9.0	66.5	300.4	10392.0	2.891
19	670241	23.0	76.5	24.4	5.1	39.9	168.9	10619.0	1.591
20	670309	139.1	75.3	18.3	31.0	39.9	303.6	8978.0	3.382
21	670313	119.3	177.4	23.0	0.	39.9	359.6	9096.0	3.953
22	670316	73.5	164.2	23.0	9.0	39.9	309.6	15174.0	2.040
23	670327	30.0	88.0	0.	25.0	66.5	209.5	10390.0	2.016
24	670341	64.8	73.0	9.3	28.5	226.1	401.7	8598.0	4.672
25	670395	89.5	141.0	2.5	24.0	0.	257.0	13630.0	1.886
26	670396	19.5	112.2	71.6	9.0	0.	212.3	10547.0	2.013
27	670420	68.4	390.5	44.6	95.3	159.6	758.4	10048.0	7.548

28	697556	154.4	117.5	4.0	32.8	119.7	428.4	10040.0	4.267
29	697560	32.0	59.2	13.0	7.0	39.9	151.1	3480.0	1.782
30	697574	128.3	140.0	0.	29.5	199.5	497.3	9311.0	5.341

TOTAL FAULTY WORKMANSHIP COST:$ 49853.2 PERCENT OF REWORK: 23.293

TOTAL MATERIAL FAILURE COST: $ 84539.1 PERCENT OF REWORK: 39.499

TOTAL CANNIBALIZATION COST: $ 10245.4 PERCENT OF REWORK: 4.787

TOTAL OTHER COST: $ 20120.4 PERCENT OF REWORK: 9.401

TOTAL REFLY COST: $ 49271.0 PERCENT OF REWORK: 23.021

TOTAL REWORK COST: $ 214029.2 PERCENT REWORK: 4.243

TOTAL MAINTENANCE COST: $5442453.0

THE SAMPLE T STATISTIC: 4.574 IS GREATER THAN T CRITICAL OF 1.699

USING 95% CONFIDENCE, THE PERCENTAGE OF REWORK SHOULD BE:3.240-5.246

*

APPENDIX D

NORMALITY TEST

APPENDIX D

NORMALITY TEST

H_0: $X \sim N\ (4.2431,\ 7.213962)$
H_1: $X \nsim N\ (4.2431,\ 7.213962)$

(i) RANK	(X) VALUE	Z_i	F(X)	$\frac{i-1}{n}$	S(X)	D	i/n	S(X)	D
1	.888	-1.249	.1056	1 - 1/30	0	.1056	1/30	.0333	.0723
2	1.597	- .985	.1611	2 - 1/30	.0333	$\boxed{.1278}$	2/30	.0666	.0945
3	1.648	- .966	.1660	3 - 1/30	.0666	.0994	3/30	.1000	.0660
4	1.782	- .916	.1788	4 - 1/30	.1000	.0788	4/30	.1333	.0455
5	1.827	- .899	.1841	5 - 1/30	.1333	.0508	5/30	.1666	.0175
6	1.886	- .887	.1867	6 - 1/30	.1666	.0201	6/30	.2000	.0133
7	2.013	- .830	.2033	7 - 1/30	.2000	.0033	7/30	.2333	.0300
8	2.016	- .829	.2033	8 - 1/30	.2333	.0300	8/30	.2666	.0633
9	2.040	- .820	.2061	9 - 1/30	.2666	.0605	9/30	.3000	.0939
10	2.407	- .684	.2483	10 - 1/30	.3000	.0517	10/30	.3333	.0850
11	2.408	- .683	.2483	11 - 1/30	.3333	.0850	11/30	.3666	.1183
12	2.795	- .539	.2946	12 - 1/30	.3666	.0720	12/30	.4000	.1054
13	2.891	- .503	.3085	13 - 1/30	.4000	.0915	13/30	.4333	$\boxed{.1248}$
14	3.382	- .321	.3745	14 - 1/30	.4333	.0588	14/30	.4666	.0921
15	3.878	- .136	.4443	15 - 1/30	.4666	.0223	15/30	.5000	.0557
16	3.881	- .135	.4443	16 - 1/30	.5000	.0557	16/30	.5333	.0890
17	3.953	- .108	.4562	17 - 1/30	.5333	.0771	17/30	.5666	.1104
18	4.267	.009	.5000	18 - 1/30	.5666	.0666	18/30	.6000	.1000

NORMALITY TEST (Continued)

(i) RANK	(X) VALUE	Z_i	F(X)	$\frac{i-1}{n}$	S(X)	D	i/n	S(X)	D
19	4.466	.083	.5319	19 - 1/30	.6000	.0681	19/30	.6333	.1014
20	4.672	.160	.5636	20 - 1/30	.6333	.0697	20/30	.6666	.1030
21	5.286	.388	.6517	21 - 1/30	.6666	.0149	21/30	.7000	.0483
22	5.341	.408	.6591	22 - 1/30	.7000	.0409	22/30	.7333	.0742
23	5.455	.451	.6736	23 - 1/30	.7333	.0597	23/30	.7666	.0929
24	5.574	.495	.6915	24 - 1/30	.7666	.0751	24/30	.8000	.1085
25	5.779	.572	.7157	25 - 1/30	.8000	.0843	25/30	.8333	.1176
26	7.141	1.079	.8599	26 - 1/30	.8333	.0266	26/30	.8666	.0067
27	7.548	1.230	.8907	27 - 1/30	.8666	.0241	27/30	.9000	.0093
28	8.189	1.469	.9292	28 - 1/30	.9000	.0292	28/30	.9333	.0041
29	10.205	2.220	.9868	29 - 1/30	.9333	.0535	29/30	.9666	.0202
30	12.096	2.924	.9982	30 - 1/30	.9666	.0316	30/30	1.000	.0018

$$Z_i = \frac{X_i - \overline{X}}{S}$$

$$\overline{X} = \sum_{i-1}^{n} \frac{X_i}{n} = 4.2431$$

$$S^2 = \left[\frac{1}{n-1}\right] \sum_{i=1}^{n} \left[X_i - \overline{X}\right]^2 = 7.213962$$

$$S = 2.6858819$$

CRITICAL VALUE

P_R [MAX D $\geq$ .886] = .05 = α

MAX D = .1278

.1272 < .886

$\therefore$ cannot reject H_0

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BIOGRAPHICAL SKETCHES

Captain John B. Berry received his Bachelor of Science degree in Engineering Sciences from Arizona State University and was commissioned as a Distinguished Graduate from Officer Training School in 1970. Following graduation from Aircraft Maintenance Officer School as a Distinguished Graduate, Captain Berry held positions of OMS Maintenance Supervisor, FMS Maintenance Supervisor, Wing Job Control Officer, and NAF Industrial Engineer. Prior to entering AFIT, he was a NAF Management Analyst at Ogden Air Logistics Center. Captain Berry's next assignment is to the Logistics Management Center at Gunter AFB, Alabama.

Mr. Raymond M. Hines received his Bachelor of Science degree in Electrical Engineering from Fresno State College in 1962. From 1962 to 1965 Mr. Hines worked as Project Engineer in the Service Engineering Division at Norton AFB, California. In 1965, Mr. Hines transferred to McClellan AFB, California where he worked as Communications Engineer for Headquarters Western GEEIA Region. From 1966 until his admission to AFIT in 1975, Mr. Hines was assigned to the Service Engineering Division at McClellan AFB, California. During this period he worked as Value Engineer and Project Engineer. Mr. Hines is a member of the Society of Logistics Engineers and the Sigma Iota Epsilon National Honorary Management Fraternity.